EFFECTS OF HIGH AMBIENT TEMPERATURE DURING EARLY, MID AND LATE GESTATION IN GILTS

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EFFECTS OF HIGH AMBIENT TEMPERATURE DURING

EARLY, MID AND LATE GESTATION IN GILTS

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INTRODUCTION

Operating confinement swine facilities at peak capacity year round has been particularly difficult in regions of high summer temperatures. Producers report that reproductive performance of sows and gilts during summer months is oftentimes below expectations. This has been expressed in terms of lowered conception rates, smaller litters, lighter pigs and fewer pigs weaned.

Due to the large investment requirement, confinement facilities must be operated at capacity throughout the year. In order to provide optimum management conditions that will insure consistent numbers of healthy, vigorous pigs for these facilities throughout the year, an understanding of how or when heat stress might affect reproductive performance is needed. This study was initiated to investigate the possible influence of high ambient temperatures at various stages of gestation. A total of 126 sexually mature gilts were used to evaluate the effects of heat stress during the first two weeks of gestation, during mid-pregnancy and during late pregnancy.

CHAPTER II

LITERATURE REVIEW

The influence of heat stress is dependent upon length and magnitude of high temperature exposure, as well as the species being exposed. In this chapter, the review of literature is presented according to the specific period of the reproductive cycle at which heat stress was applied and according to specie involved.

General Observations

Cattle

Seasonal fluctuations in reproductive efficiency seem to be the first indication of possible effects of temperature and humidity on the normal processes of reproduction. Poston et al. (1960) stated that a ten-year summary of breeding records from six herds of dairy cows showed a gradual increase in percent of cows bred that returned to estrus within 60 to 90 days as temperatures at time of breeding increased. This increase ranged from a low of 38% when breeding occurred in January to a high of 56% in August. The number of services required per conception also increased from an average of 1.7 for cows calving in December to 3.0 for those calving in April.

A differential effect of season on conception rate in 642 first-calf heifers and 593 cows of the Holstein and Jersey breeds was reported by Hillin and Rupel (1960). This study was carried out under climatic

conditions indeginous to south Texas. Season of breeding seemed to be more important in Holstein heifers since they required an average of 3.12 services per conception when bred from June through October as opposed to 2.11 when bred during the cooler months. Similarly, Holstein cows bred during the summer months required 2.36 services per conception and 1.87 during the cooler months. The effects of season were less marked among Jersey heifers and cows in that they required 2.13 and 2.02 services per conception for the summer months and 2.09 and 1.96 services per conception for the cooler months, respectively.

Stott and Williams (1962) bred 406 Holstein two-year old cows during June, July, August and September which are the critical high-temperature months for Arizona. From their results it was postulated that a low rate of fertilization and high embryonic mortality are major factors associated with low seasonal breeding efficiency and the time of breeding was the most critical period for heat stress.

Swine

Ahlschwede and Robison (1966), working with 937 Duroc, Yorkshire and crossbred litters of swine over a five-year period, analyzed climatic variables at time of breeding and for two days afterward. They found that no combination of variables accounted for more than 2% of the total variation in litter size but there was an indication that temperature variations on the second day were more important than on the day of breeding.

Sanders et al. (1964) showed that mean body temperature was higher for swine kept at 85°F than for those kept at 70°F. He also suggested a possible association between ovulation rates and temperature but, due to small numbers, definite proof was lacking.

Whatley et al. (1957) noted a significant ($P<.05$) increase in pigs born live per litter for sows maintained during summer in lots equipped with sprinkler-shades when compared to those with shades only. This difference manifested itself in 2.05 ($P<.01$) more pigs weaned per litter and an 85.41 lb. ($P<.01$) advantage in litter weaning weight for sprinkled sows.

Sheep

Shelton and Morrow (1965), when breeding Rambouillet ewes around the longest and shortest days of the year, as well as the two periods of equinox, found season of the year to be the major factor affecting occurrence of estrus and ovulation rate. They found ovulation rates to be highest at September matings, while highest lambing rate followed December matings. Occurrence of estrus was lowest in March and highest in December. They also noted that lambing results, particularly for June and September mating periods, were substantially modified by high environmental temperature.

Goode (1964) described a situation in sheep he called a "Fall Lamb Syndrome". He described this as the occurrence of small, weak lambs from ewes lambing at the end of a hot summer. Abortions and premature lambs were also common and 38% of the lambs born were dead or failed to survive one week. Approximately 30% of the ewes mated failed to lamb at all. When Dorsets ewes, bred to lamb in the fall, were maintained at 2-4°F below outside control lot temperatures, birth weights were increased by 1.07 lbs. ($P<.01$) and lamb survival and percent ewes lambing were also improved.

Alliston et al. (1961) demonstrated a marked advantage for cooling ewes to 65°F at time of mating when the average maximum temperature was 91.4°F. Conception and lambing rates were increased in the cooled ewes but little or no advantage was discovered for cooling rams at this time.

A significant effect of date of lambing on birth weights of 1600 lambs was reported by Shelton (1964). He used records spanning several years and found that seasonal effect was most pronounced in fall-lambing programs. Lamb weights ranged from 6.9 lbs. in mid October to 10.2 lbs. for the third week of December. In two experiments involving 103 ewes he compared 100-105°F temperatures during gestation to 75-80°F temperatures during the same period. Results indicated that high temperature significantly reduced birth weights and tended to increase lamb mortality.

Godley et al. (1966) increased lambing percentage in ewes over a three-year period by using a combination of lowered temperature (21.1°C) and decreased hours of light (10.4-11.4 hrs.) during summer months. This combination resulted in a 91.3% lambing rate for treated ewes compared to 53.7% for outside controls.

Mice

Ogle (1934) pointed out that white mice subjected to a warm humid environment tend to have low conception rates, small litters and low viability of offspring. She also noted that mice tend to reach puberty earlier and are generally more efficient in sex function when maintained in a steady cool environment.

From these reports, it can be seen that high temperature effects on reproductive performance are manifested in varying degrees and at varying stages of gestation. Pin-pointing the exact period or periods

of critical influence and gaining some insight as to mechanisms by which temperature has its effect has been the object of considerable research in several species.

Heitman et al. (1949) concluded the direct result of high ambient temperature on swine was increased respiration rates and body temperatures. They suggested that lowered feed consumption and efficiency were results of unusually high temperatures. How these can be applied to explanations of lowered reproductive efficiency is not readily apparent.

Nalbandov (1952) suggested the possibility that heat stress may cause lowered fertilization as a result of a faulty synchronization between onset of estrus and time of ovulation. In the study by Stott and Williams (1962), more cows exhibited an unusually long estrous cycle (in excess of 26 days) following a non-fertile mating in the hot summer than following a non-fertile mating in a cool season.

Ulberg and Buferning (1967) stated that a slight increase in temperature on sperm before fertilization or on ova after fertilization can cause embryos to die some time later in their development. Stage of embryo development when stress is applied is very critical in terms of subsequent cellular division before death. Stress during the first cleavage is more detrimental than in later cell-division. Ulberg (1958) concluded that ova under constant high temperature may be affected directly prior to fertilization but less severe or variable temperature may bring about a change in uterine environment causing death of the embryo prior to time of implantation.

Early Gestation

Laboratory Animals

Rich and Alliston (1970a) used rabbits to test acclimation and post-acclimation effects of heat stress on ovulation rates, fertilization rates, embryonic survival and ova transplant success. They found no significant effect on ovulation or fertilization rates for any treatment. However, the does stressed in some way tended to have more complete fertilization failures than cooled does. Embryo survival for non-transferred zygotes seemed to be depressed by heat stress and was largely due to post-implantation death. Death loss for transferred zygotes was similar for cool and fluctuating temperature but more severe in constant high temperature. There seemed to be an indication that manual manipulation of zygotes made them less tolerant to heat stress.

Aldred et al. (1961) subjected mice to varying lengths of exposure to 104°F temperature on the first and second days following mating. They found an increase in embryo loss with added exposure from 14% in controls to 32.5% for those subjected to five hours of stress on day one and two. The effect of temperature on day one was found to be more pronounced than on day two.

Macfarlane et al. (1957) stated that Wistar rats lost up to 58% of their fetuses when subjected to 35°C compared to a loss of only 7% when maintained at 22-28°C. They also acclimated the rats by placing them in a 35°C environment for two to ten weeks prior to mating and significantly reduced the rate of fetal resorption. However, numbers of corpora lutea formed were significantly reduced by acclimation.

Hsu (1948) incubated Wistar rats at 39°C for either one hour or four hours at various times from 0.5 to 10.5 days after insemination.

This temperature terminated pregnancy in some rats, the percentage of which was greater when treatment was applied earlier. Some embryos survived when stressed during early cell division but because of this stress did not survive the subsequent process of implantation.

Alliston and Ulberg (1965) cultured four and eight-cell ova in vitro for six hours at temperatures corresponding to both normal (38°C) and elevated (40°C) rectal temperatures. After incubation, ova were placed in psuedopregnant females and autopsy was performed 12 days post-coitus. They found no direct effect of temperature on these ova and concluded that detrimental effects of temperature must occur before first cleavage.

In support of these arguments, Alliston et al. (1965) using one and two-cell rabbit ova found increased post-implantation mortality of one-cell ova cultured at 40°C compared with normal cultures or ova that had cleaved. They concluded that a direct effect of thermal stress on the early embryo might not manifest itself until later stages of embryonic development.

Shah (1956) placed heat-stressed embryos in untreated rabbits with good results but when placing normal embroys in heat-stressed does, embryo loss was high. He stated that high temperature stress in rabbits during the first six days of gestation interrupted normal pregnancy and that maternal tissue was directly affected rather than the embryos themselves.

Elliot et al. (1968) recovered mouse ova at the time of first cleavage after being stressed in vivo. They then cultured the ova through the blastocyst stage in vitro as well as in vivo and obtained a significant ($P<.05$) decrease in number of heat-stress embryos cultured

in vitro that became blastocysts. They concluded that direct stress on the embryo was apparent and that maternal environment was not the key factor in embryo loss for this study.

Sheep

Ryle (1961) acclimated ewes to a hot environment for one estrous cycle prior to breeding and compared them to those kept outside. The 24 acclimated ewes had a total of 14 embryos as compared to 27 embryos for the outside-control ewes. This indicated a marked disadvantage for a hot environment in this study.

Dutt et al. (1959), when exposing ewes to 90°F starting on day 12 of the estrous cycle prior to breeding, found that fertilization rates for stressed ewes were significantly ($P<.01$) lower than for ewes kept outside. In control ewes, 92.6% of the ova cleaved compared to 51.9% for heated ewes. When heat stress was delayed until eight days post-breeding, 15.4% embryo loss was noted but this was not significant. Heat stressing ewes at eight days resulted in 17 of 20 ewes lambed as opposed to one of 20 when stress was applied before breeding. They stated that sheared ewes were intermediate in their response to heat stress and this indicated an additive temperature effect.

Columbia and Rambouillet ewes, exposed to 21.1°C continually or to a fluctuating environment between 21.1 and 32.2°C, were observed by Rich and Alliston (1970b). They found no significant effect of treatment but there was a tendency for more of the ewes exposed to fluctuating temperature to be open at 35 days postbreeding. This was associated with embryonic death loss and not to lowered fertilization or ovulation rates.

Smith et al. (1966) subjected Merino ewes mated to Southdown rams to high temperature for seven days starting after onset of estrus. They detected a significant reduction in the incidence of viable embryos at 21-24 days post-coitus in heat-stressed ewes. Ewes had normal estrous cycles following non-fertile matings.

Dutt (1963) placed ewes in 90°F stress on day zero, one, three and five of gestation and noted a slightly lower non-significant fertility rate compared to control ewes. Heat stress resulted in an increase in morphologically abnormal ova with 3.7% abnormal ova for controls, 46.2% for day zero and 30.8% for day one. Days zero and one combined had significantly higher embryo loss than for days three and five together. He stated that the zygote was most sensitive to high temperature during initial cleavage since 18 of 20 ewes stressed on either day zero or day one returned to estrus. He further stated that induction of embryo death after it enters the uterus may result in abnormal estrous cycle duration. In his study, 85% of control ewes lambed while only 10% of day zero and one, 35% of day three and 40% of day five ewes lambed.

In two experiments, using 40 Merino and 40 Southdown ewes, Thwaites (1967) applied heat stress for 20 days after breeding and increased rectal temperature by 2.5°F. Respiration rate was increased by 150 per minute compared to 20 per minute for normal sheep. All of the embryos in treated ewes were lost, 75% of which died early in pregnancy since the estrous cycle was not lengthened significantly. The remaining 25% had degenerating embryos at day 23 of gestation.

In a similar study, Thwaites (1969) exposed Merino ewes for the first 15 days of pregnancy, raising rectal temperatures to 104-105°F and respiration rate to 170 per minute. Stressed ewes lost 83% of their

embryos. He then tested a diurnally variable system of stress in which 104°F rectal temperatures and a respiration rate of 220 per minute for eight hours a day were attained. During the remaining 16 hours of the day, rectal temperatures were allowed to fall to 102°F with respirations at the rate of 140 per minute. This system resulted in a death loss of 35% of the embryos as compared to 19% loss in controls. It was suggested that a daily respite from high temperatures was a major factor to be considered when comparing hot room results to actual field conditions.

Alliston and Ulberg (1961) studied early embryo development in ewes kept at 70 and 90°F by transferring ova at 72 hours post-coitus, successful transfers being noted by laporatomy 25-30 days later. In order to measure effects of laporatomy and transfer procedures, embryos from ewes in 70°F were transferred to other ewes in the same environment, 56.5% of which were successful. Only 9.5% of 90 to 70°F transfers were successful. This indicated detrimental effects prior to three days post-coitus. In 70 to 90°F transfers, an intermediate number of successes were noted suggesting some effect of temperature after three days.

Analagous environmental conditions were used by Woody and Ulberg (1964) in transferring one-cell sheep ova. When ova were placed in 70°F environment upon transfer, no differences were noted, but when either 70 or 90°F ova were transferred to a 90°F environment, a reduction of viability was noticed. This study stressed the importance of heat stress of the ewe during early embryo development.

Swine

Payer (1971) stressed gilts from the 15th day of the estrous cycle

prior to breeding using 96°F for eight and one-half hours daily and 90°F for the remainder of the day. Following breeding the gilts were removed from stress conditions. He found no significant effect of heat stress prior to breeding of gilts. A daily respite from high temperature during the cycle may allow relatively normal reproduction in gilts.

d'Arce et al. (1970) evaluated effects of high ambient temperature and humidity prior to estrus in terms of numbers of corpora lutea and estrous cycle length. Heat stress was varied primarily, by changing dew point temperature for varying periods of time in Duroc gilts. Environment had no significant effect on the corpora lutea, however increased duration of stress tended to reduce ovulation rate. There was a marked variation in corpora lutea development for gilts exposed to high temperature for the complete estrous cycle.

Teague et al. (1968) administered varying dry and wet bulb temperatures on 240 Duroc gilts for one estrous cycle prior to breeding. Slaughter at 25 days post-breeding revealed a decrease in percent of gilts pregnant with increasing dry bulb temperature. Dry bulb temperature was more adverse in its effect than dew point temperature. Increasing dry bulb temperature significantly ($P<.05$) decreased ovulation rates but no differences were noted in numbers of live embryos. It was indicated that an interaction between dry bulb and wet bulb temperature was probable but not necessarily additive.

Edwards et al. (1968) evaluated the effects of a diurnal heat stress environment (17 hours of 38.9°C and seven hours of 32.4°C) as compared to maintaining gilts at 23.4°C continuously, prior to breeding as well as during early gestation. Gilts exposed to stress for the entire estrous cycle prior to breeding had significantly ($P<.05$) longer

estrous cycles than controls. When subjected to stress for three to five days prior to breeding, no effect on estrous cycle length was noted. Neither of these groups gave any evidence of heat stress effects on ovulation or fertilization rates. Gilts submitted to heat stress during the first 15 days after breeding, had lower conception rates, fewer ($P<.01$) viable embryos and lower ($P<.01$) survival rates than either gilts maintained in the cool chamber or in outside pasture lots. They concluded that heat stress was more critical during early gestation than prior to breeding and that the embryo was more susceptible to heat stress effects in the stages of development associated with implantation.

Warnick et al. (1965) stressed gilts starting 10 days after first estrus and continuing through breeding until slaughter 25 days later. There were no significant differences in ovulation rate, but some gilts, maintained at 90°F continuously, ovulated without visible signs of estrus. An average of 1.9 more embryos were found in gilts kept at 60°F continuously as compared to 90°F but this was not significant. When heat-stressed gilts were switched to cool chambers after three days pregnancy, they had 2.3 ($P<.05$) more embryos than gilts, first maintained in a cool environment, then switched to heat stress after three days. They deemed a 90°F environment as moderate stress in reproductive performance of swine.

Postbreeding thermal stress was investigated by Tomkins et al. (1967) by varying onset and duration of high temperature. They found that the percentage of live embryos was decreased in all cases when stress was applied on the first day following breeding. They concluded that the first five days of pregnancy was a more critical period for detrimental effects of high temperature in swine than later in gestation.

Mid and Late Gestation

Sheep

The influence of thermal stress on the sheep fetus was studied by Alexander and Williams (1971). Temperatures of 40°C for nine hours and 32°C for 18 hours were used as stress conditions during middle third, final third or final two-thirds of pregnancy. Birth weights and placenta weights were considerably reduced, which could not be attributed completely to lowered feed consumption. They ruled out the possibility of fetal dwarfing as an effect of heat stress because body organs and skeletal structures of the lambs were of normal proportions. They noted cavities in the white matter of the cerebral hemisphere of heat treated lambs but did not comment on their significance.

Shelton (1965) found that a constant heat stress of 32°C during the last 100 days of pregnancy virtually eliminated reproduction in 56 fine-wool ewes. Cooled ewes had 78.6% of their group lambing with average lamb weights of 6.9 lbs. while only 14.3% of the heated ewes lambed. These lambs averaged 2.2 lbs. and none of them survived. In a seven-year study, Shelton (1968) placed ewes in temperature control chambers during the last one-half to two-thirds of gestation and varied the amount of high temperature stress per day. Lambs from cooled ewes had heavier ($P<.01$) birth weights and higher ($P<.05$) survival rates. Exposure to 12 hours of heat stress per day seemed intermediate in its results and a possibility of additive effects of heat stress were suggested. He stated that high temperatures could reduce gestation length from five to seven days and this would explain a large part of the reduced weights of lambs.

Yeates (1953) found that exposing ewes to high temperatures for two months prior to the normal breeding season had no effect on occurrence of estrus but when treatment was continued through pregnancy, only one of six lambed. When stressing ewes during the final two-thirds of pregnancy, three of six ewes failed to lamb. He concluded that high temperature affected estrus very little but was highly detrimental to satisfactory gestation.

Yeates (1958) compared high and low planes of nutrition to a combination of low nutrition and thermal stress in evaluation of the possibility of fetal dwarfing. All ewes in high and low nutrition groups lambed with a significant advantage ($P<.01$) for high nutrition when lamb weights were analyzed. Only four of seven heat-stressed ewes lambed and their birth weights were smaller ($P<.01$) than those on the low plane of nutrition. X-rays of lambs showed a dwarf type skeletal structure for lambs from stressed ewes which could not be detected in lambs from ewes on low nutritional diets.

In relation to fetal dwarfing and heat stress, Alexander (1964) showed that removing caruncles from maternal tissue was compensated for by increased cotyledon size in the placenta and that the placenta size was important to fetal weight especially after 100 days pregnancy in sheep. If high temperature should cause a loss in placenta size as suggested by Alexander (1971), then reduced birth weight would be expected and could be a result of fetal dwarfing.

Swine

Very little work has been published concerning heat stress effects on sows and gilts during late pregnancy. However, Heitman et al. (1951)

placed 14 sows of varying ages in a control chamber on the 85th day of pregnancy. They started at 70°F and worked upward in five degree increments until a definite rise of body temperature was noted and maintained that temperature 24-72 hours. Maximum temperature reached was 99°F. At farrowing 11 of 13 sows had pigs, one of which died of heat prostration and one aborted only a short time after being placed on treatment. They concluded that high temperatures at this time in gestation would cause death of the sow before disturbing the well-being of the fetus.

Whatley et al. (1957) found a marked detrimental effect of high summer temperatures (96.0 to 108.5°F) on numbers of pigs born live ($P<.05$) and average litter weights at weaning ($P<.01$). This difference was found when comparing gilts provided with a sprinkler-shade system to those with shades only. Temperatures under these conditions were 96.0 to 104.5°F.

Hormonal Mediation

Adrenal

In many of the articles previously mentioned, postulations of thyroid and adrenal gland mediation in the process of heat tolerance were prevalant. For example, Dutt (1963) mentioned a possible adrenal disturbance as a mediator for harmful effects of heat stress in sheep. Likewise, Fernandez-Cano (1958) suspected an adrenal gland influence on degeneration of rat ova when heat stress was applied.

Howarth (1969) used rabbits in an attempt to determine if the adrenal glands could be implicated as a mediator of early embryonic mortality due to heat stress. He found an indication that adrenalectomized does were not as efficient in initial ability to regulate

body temperature and adrenalectomy did not improve fertility. In fact, it lowered the rate of implantation and caused more abnormally divided ova. This suggested a possible importance of the adrenal gland during early cell division.

Thyroid

Probably more important to researchers has been the possibility of thyroxine being a mediator in heat stress effects. Ryle (1961) listed thyroxine level in sheep as an important factor in fertility studies. Shelton (1965) and Alexander (1971), in separate studies with sheep, found thyroxine administration to be detrimental, causing reduced birth weights and a tendency toward increased embryo mortality.

d'Arce (1970) measured a decrease ($P<.01$) in blood thyroxine levels in swine exposed to high temperature but could not directly associate this to reproductive efficiency. In rats, Macfarlane (1957) noted a decrease in resorption of fetuses when administering thyroxine but differences were not significant.

Hoersch et al. (1961) demonstrated that high temperatures lower the thyroxine levels in the blood. It is not known whether or not thyroxine is a mediator of embryonic mortality induced by heat stress. Thwaites (1970) dismissed this possibility as not being critical and stated that changes in the luminal fluids of the Fallopian tubes and uterus are probably the most likely mechanism of heat-induced embryo mortality in the ewe.

Yousef et al. (1967), working with Holstein cows, noted a relation of temperature to blood thyroxine levels and provided some evidence that thyroid function and metabolic rate are involved in the compensation

stage of acclimation to new environmental temperatures. They stated that thyroid function took little part in ititial shock but may have a definite role in the acclimation process.

CHAPTER III

MATERIALS AND METHODS

This study was conducted at the Ft. Reno Livestock Research Station, El Reno, Oklahoma, in cooperation with the U. S. Department of Agriculture. The environmental control unit, consisting of two 12 ft. by 12 ft. temperature controlled rooms as previously described by Payer (1970) and Edwards et al. (1968), were used in this study.

In this experiment, hot chamber environment consisted of a 17 hour period (4 p.m. to 9 a.m.) of very high temperature (37.8°C) and a seven hour period (9 a.m. to 4 p.m.) of moderate temperature (32.2°C). Although humidity was not directly controlled, it remained fairly stable ranging from 38 to 42% during the period of elevated temperature and ranging from 48 to 52% when the chamber temperature was maintained at 32.2°C. The control chamber environment was maintained at 23.3°C continuously and the relative humidity stablized between 58 and 62%. It might be noted that humidity increased sharply in both chambers for a short period immediately after being cleaned. Humidity at this time reached as high as 74% in the control chamber and 60% in the hot chamber. All temperatures and humidities were recorded continuously by a geothermograph inside the chambers at approximately floor level. Artificial light was provided 24 hours per day during this study.

In August and September of 1968, 63 crossbred gilts were mated to crossbred boars and allotted at random to one of nine treatments as

TABLE I

DESCRIPTION OF TREATMENTS

Stage of gestation	Treatment number	Chamber	Period of confinement (days postbreeding)	No. gilts allotted	Disposal of gilt
Pre-Implantation	1	Hot	0-8	14	Slaughter
	2	Control	0-8	14	Slaughter
Implantation	3	Hot	8-16	14	Slaughter
	4	Control	8-16	14	Slaughter
Mid Pregnancy	5	Hot	53-61	14	Farrow
	6	Control	53-61	14	Farrow
Late Pregnancy	7	Hot	102-110	14	Farrow
	8	Control	102-110	14	Farrow
Control Group	9	Outside	0-110	14	Farrow

shown in Table I. In February and March of 1969, the same procedure was followed using 63 Hampshire gilts mated to unrelated crossbred boars. All gilts used in this experiment had been observed to exhibit two normal estrous cycles prior to breeding. All were first-litter gilts and were mated between 11 and 12 months of age. This allotment resulted in seven gilts in each treatment within each season or a total of 14 gilts per treatment.

All gilts were confined for a period comparable to eight nights of highest temperatures in the hot chamber. Approximately 30 minutes at 9 a.m. and again at 3:30 p.m. was allotted for feeding the gilts and cleaning the chambers. During this time the gilts were removed from the chambers and fed in individual stalls. Gilts in early and mid pregnancy received 1.1 kg. of the ration shown in Table II at each feeding. Gilts in late gestation received 1.3 kg. of feed at each feeding. It was felt that an adequate level of nutrition was maintained for proper development for all gilts used in this study.

TABLE II

BREEDING HERD RATION

Ingredient	Amount
Wheat	994
Milo	500
Soybean meal (44%)	260
Tankage	100
Alfalfa pellets	100
Dicalcium phosphate	20
Ground limestone	6
TM salt	10
Premix	10
TOTAL	2,000

Crude Protein=17.0%; Ca.=0.81%; P.=0.71%

Gilts, when not confined to a chamber, were kept in outside pasture lots equipped with self waterers, sow houses and sprinkler-shade systems. Feeding regime was similar to that described for gilts in confinement. Individual feeding stalls were located in each pasture lot.

Minimum body temperature was estimated at approximately 4 p.m. or immediately prior to elevation of the temperature in the hot chamber. Previous observations showed that maximum body temperature was reached within four hours after exposure, so the rectal temperatures were also taken at approximately 8 p.m., four hours after increasing the temperature. It was at these times that daily rectal temperatures were recorded for gilts in both chambers using standard rectal thermometers.

Gilts allotted to the first four treatments were transported to the Wilson Packing Company, Oklahoma City, for slaughter on a weekly basis. This resulted in gilts being slaughtered over a range of 28 to 37 days postbreeding. The reproductive tracts were recovered and brought back to the Physiology Laboratory for further evaluation. Ovaries were dissected to determine number of corpora lutea and the tracts dissected to obtain the embryos. Embryo length was measured from crown to rump on viable embryos while encased in the amnionic sac.

Gilts in treatments five through nine were allowed to go full term to farrowing. Number of pigs farrowed (live and dead) and individual pig weights were obtained at birth. All gilts farrowed in the central farrowing facilities and pigs were not given access to creep feed until after 21-day pig weights were obtained.

Numbers of corpora lutea were different for the groups of gilts in each treatment in this study. Statistical analysis of embryo numbers was carried out following procedures described by Harvey (1960). In

this way, corpora lutea numbers were adjusted so that valid comparisons of embryo numbers could be made. Similarly, age of embryos were adjusted when comparing embryo lengths. These covariables, using this technique, can be fit into the following mathematical model given by,

$$Y_{ijk} = \mu + \beta_1 (X_{ijk} - \bar{X}^{\cdot\cdot}) + r_i + t_j + e_{ijk}$$

where,

Y_{ijk} = individual observation of number of live embryos or average embryo length

μ = mean number of live embryos or average embryo length.

β = a regression coefficient for the effect of either number of corpora lutea or days pregnant, X_{ijk} covariables, with $\bar{X}^{\cdot\cdot}$ being the overall mean associated with the appropriate covariable.

r_i = an effect of the ith replication (i_1 = Rep 1, i_2 = Rep 2).

t_j = an effect of the jth treatment (j_1 = Treatment 1, j_2 = Treatment 2, j_3 = Treatment 3 and j_4 = Treatment 4).

e_{ijk} = the failure of the stated model to estimate number of live embryos or average embryo length.

The resulting components of variance are shown in Table III.

All other statistical comparisons used in this study utilized analysis of variance methods described by Snedecor and Cochran (1967). For example, the analysis of pig numbers born live per litter can be carried out by using the mathematical model given by,

$$Y_{ij} = \mu + r_i + t_j + (rt)_{ij} + e_{ij}$$

TABLE III

ANALYSES OF VARIANCE FOR NUMBER OF LIVE EMBRYOS AND AVERAGE EMBRYO LENGTH

Source	df
Total	47
Mean	1
Covariable[1]	1
Replication	1
Treatment	3
Error	41

[1]Covariables were either number corpora lutea held constant for number of live embryo analysis, or days pregnant held constant for embryo length analysis.

where,

Y_{ij} = individual observation of number of pigs born live.

μ = mean number of pigs born live.

r_i = an effect of the ith replication (i_1 = Rep 1, i_2 = Rep 2).

t_j = an effect of the jth treatment (j_1 = Treatment 5, j_2 = Treatment 6, j_3 = Treatment 7, j_4 = Treatment 8 and j_5 = Treatment 9).

$(rt)_{ij}$ = an effect for the interaction of the ith replication with the jth treatment.

e_{ij} = failure of the stated model to estimate number of pigs born live.

The resulting components of variance for this response are given in

Table IV. It was found that replications were not significantly different so the results for both seasons were combined in each treatment. The analyses of all other variables in this study are given in the Appendix.

TABLE IV

ANALYSIS OF VARIANCE FOR NUMBER OF PIGS BORN LIVE PER LITTER

Source	df
Total	67
Reps	1
Within treatment	6
Rep x Block	6
Treatments	4
Rep x Treatment	4
Error	46

CHAPTER IV

RESULTS AND DISCUSSION

In this chapter, rectal temperatures and reproductive performance of the gilts during early, mid and late pregnancy, are presented and discussed. The analyses of variance for these variables are presented in the Appendix.

Rectal Temperatures

Rectal temperatures of gilts confined to environment chambers are shown in Figures 1, 2, 3 and 4. Gilts subjected to the control chamber during all phases of gestation tended to have relatively stable temperatures of approximately the same magnitude. The average temperature for all control-chamber gilts averaged 38.7°C ± 0.2 which was slightly below the suggested normal of 39°C for swine. This is in agreement with findings of Edwards et al. (1968). Table V gives the combined mean rectal temperatures for both the hot chamber and control chamber for each day of confinement for all four stages of gestation. Coefficients of variation are also given for comparison of within day variations. The rectal temperatures by day of confinement for each stage of gestation are given in the Appendix.

Rectal temperatures for hot-chamber gilts were significantly higher ($P<.05$) than those for the control chamber gilts in all phases

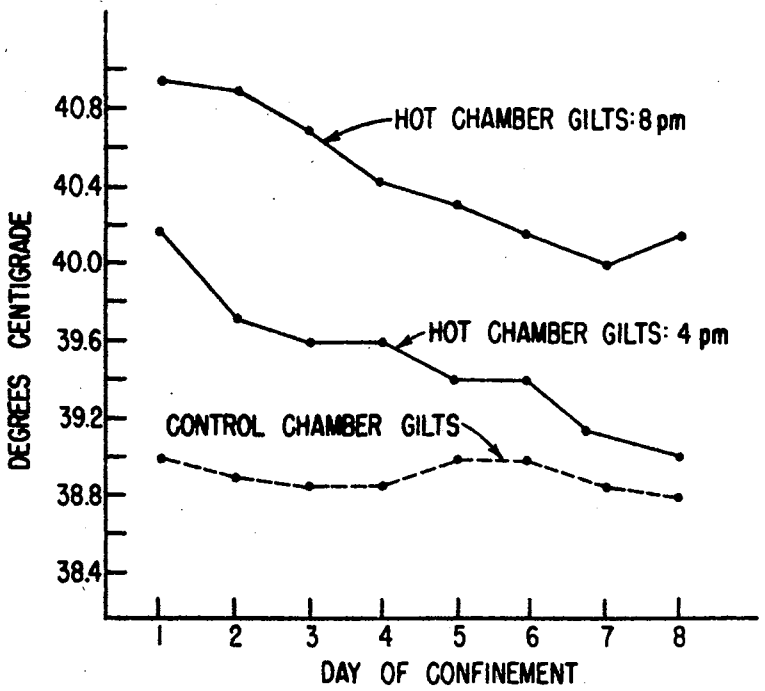

Figure 1. Average rectal temperatures of gilts confined to the chambers 0-8 days postbreeding.

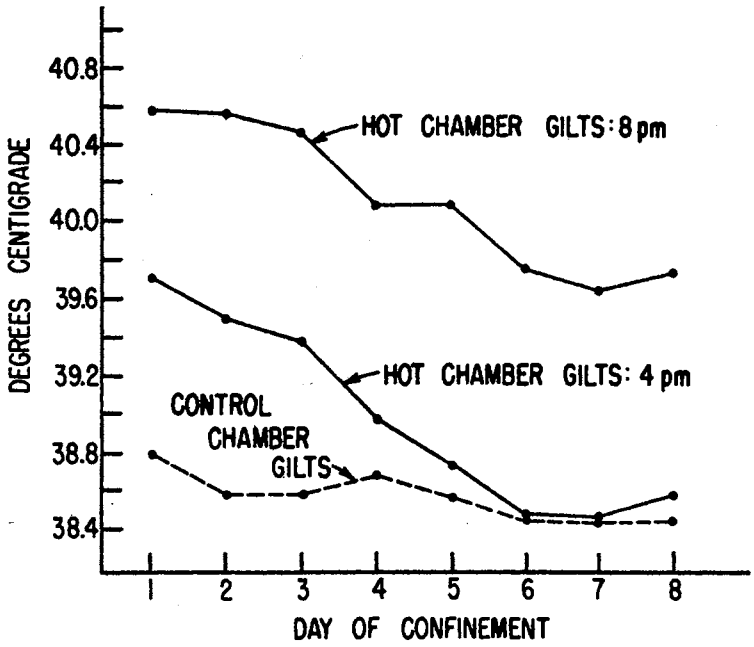

Figure 2. Average rectal temperatures of gilts confined to the chambers 8-16 days postbreeding.

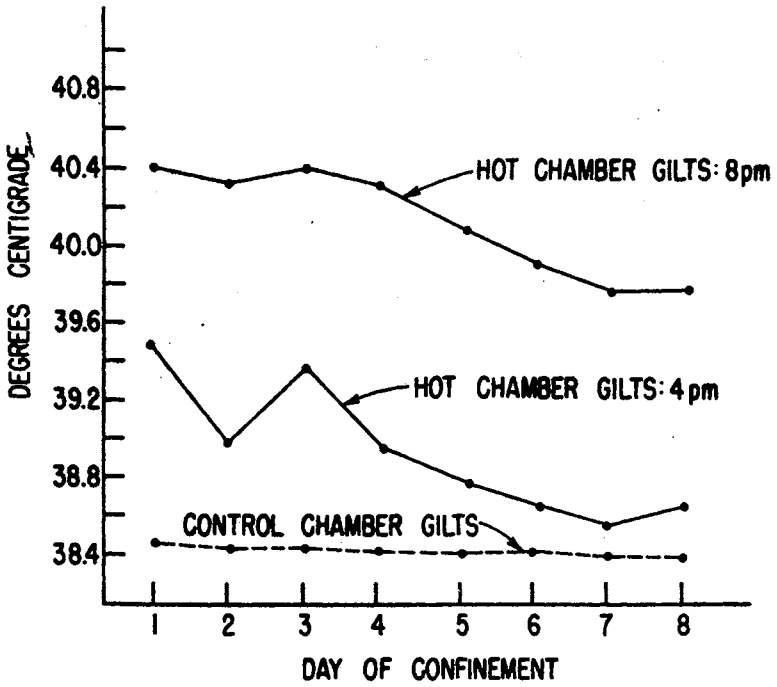

Figure 3. Average rectal temperatures of gilts confined to the chambers 53-61 days postbreeding.

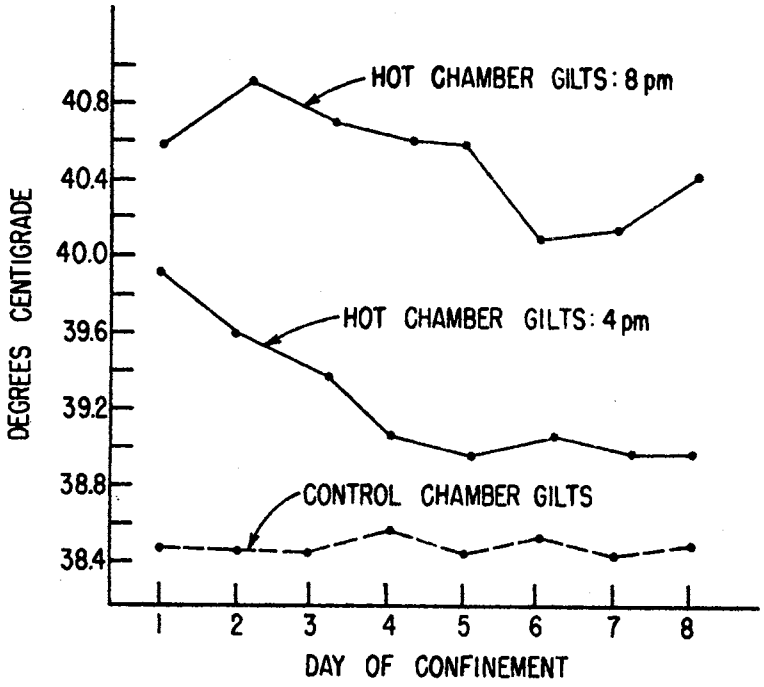

Figure 4. Average rectal temperatures of gilts confined to the chambers 102-110 days postbreeding.

TABLE V

AVERAGE RECTAL TEMPERATURES[a] AND

COEFFICIENTS OF VARIATION[b]

Day	Hot Chamber Minimum (4pm) Temp	CV	Hot Chamber Maximum (8pm) Temp	CV	Control Chamber Temp	CV
1	103.75	1.24	105.17	1.06	101.70	0.57
2	103.04	1.37	105.14	1.18	101.54	0.50
3	102.99	1.28	105.02	1.01	101.53	0.57
4	102.55	1.15	104.67	0.87	101.64	0.49
5	102.26	1.11	104.52	1.02	101.61	0.51
6	102.07	1.23	103.97	1.02	101.56	0.52
7	101.85	1.08	103.84	1.04	101.53	0.53
8	101.90	0.89	104.06	1.00	101.49	0.47

[a]Temperatures expressed in degrees Fahrenheit.
[b]Coefficients of variation expressed in percentage.

of this study. The response curves for the heat-stressed gilts were similar for all periods and rectal temperatures were elevated substantially immediately after entry into confinement. Evidence for an acclimation to hot temperature after a few days is also evident, although less pronounced in late pregnancy. This acclimation is especially apparent for minimum body temperatures which, except for those subjected to hot chamber in late pregnancy, were not significantly different from controls after six days of exposure.

Although the coefficients of variation do not reveal any marked changes in the amount of within day variation in rectal temperatures

by day of confinement, there was considerably less variation among gilts in the control chamber.

Early Pregnancy

Only 8 of 14 gilts (57.1%) exposed to the hot chamber during the first eight days of pregnancy and 11 of 14 gilts (78.6%) exposed during days 8 to 16 were pregnant at 30 days. All gilts placed in the control chamber during these periods were pregnant at 30 days. All nine of the gilts that failed to conceive when subjected to the hot chamber settled when rebred indicating that they were normal. This would suggest a detrimental effect of high ambient temperature on conception rate, probably due to embryonic death loss during early pregnancy.

Reproductive performance of gilts slaughtered in early gestation is shown in Table VI. Ovulation rates, as determined by the average number of corpora lutea, were significantly different between treatments but there was no reason to assume that this was due to the environmental treatments imposed. Edwards et al. (1968) and d'Arce et al. (1970) reported no significant differences in ovulation rates due to exposure to high ambient temperatures during estrus. An overall average of 14.8 ova shed was considered the potential number of pigs that could be produced by any one gilt.

The numbers of viable embryos were analyzed holding ovulation rates constant. The control gilts were comparable in their embryo numbers and had significantly more ($P<.01$) viable embryos than either of the heat stressed groups. A definite disadvantage was shown for gilts in a hot environment during the second eight-day period of gestation. These gilts had approximately 4.5 fewer embryos ($P<.01$) than

TABLE VI

REPRODUCTIVE PERFORMANCE OF GILTS CONFINED

TO CHAMBERS DURING EARLY GESTATION

Item	Period of postbreeding confinement				Standard error
	0-8 days		8-16 days		
	Hot chamber	Control chamber	Hot chamber	Control chamber	
No. gilts allotted	14	14	14	14	
No. pregnant at 30 days	8	14	11	14	
No. corpora lutea/gilt	14.8^{ab}	13.4^{a}	16.1^{b}	15.1^{ab}	0.58
No. viable embryos/gilt[1]	11.4^{a}	13.0^{b}	6.9^{c}	12.8^{b}	0.32
Embryo length, mm[2]	32.1	34.0	31.8	32.5	1.07

[1] Adjusted number of embryos holding number of corpora lutea constant.

[2] Adjusted embryo length holding days pregnant constant.

^{a,b,c}Values within rows with different superscripts significantly different ($P<.01$).

gilts stressed during the first eight days of pregnancy and 5.9 fewer embryos ($P<.01$) than the control group exposed to the chamber during this period. Edwards et al. (1968) found a similar effect of heat stress during the first 15 days of pregnancy but they noted a marked increase in heat tolerance during the second 15 day period.

Knowledge of the process of embryo development and the physiological changes occurring during gestation is necessary to understand why heat stress might affect a gilt during specific segments of gestation. Oxenreider and Day (1965) found that swine ova were transported through the oviduct faster than reported for sheep, cattle and many other mammalian species. They stated that the ova passed rapidly through the first half of the oviduct and then remained in the third quarter until 60 to 75 hours after onset of estrus. Perry and Rowlands (1962) were in general agreement with these findings and showed that entry into the uterus was at approximately the four-cell stage of development and early blastula stages were not reached until around 120 hours post-estrus. All of these events are probably periods of rapid change and their relative occurrence may be highly important in considering heat stress effects.

According to Nalbandov (1964), the blastocysts float free in the uterus until between days 11 and 20 of pregnancy, at which time implantation occurs. This study would indicate a highly critical effect of heat stress during the time of implantation in swine.

Embryo lengths indicated that heat stressed gilts tend to have smaller embryos but numbers were too limited for differences to be significant. These findings are similar to those of Edwards et al. (1968).

Mid Pregnancy

The reproductive performance of gilts placed in the chambers from day 53 through day 61 postbreeding and gilts kept outside until term is given in Table VII. Productivity for gilts subjected to either the hot or control chamber during mid pregnancy and those maintained outside full term was comparable. No significant differences were noted between any variables studied for these three groups. This suggests that gilts are relatively resistant to high ambient temperatures during mid pregnancy.

TABLE VII

REPRODUCTIVE PERFORMANCE OF GILTS CONFINED TO CHAMBERS DURING MID PREGNANCY COMPARED TO THOSE MAINTAINED OUTSIDE THROUGHOUT PREGNANCY

	Hot Chamber	Control Chamber	Outside	Standard error
No. gilts allotted	14	14	14	
No. farrowed	14	14	14	
FARROWING RECORDS:				
Live pigs/litter	10.3	10.8	10.7	0.76
Dead pigs/litter	0.7	2.2	1.0	0.62
Avg. pig wt., kg.	1.3	1.3	1.3	0.05
Avg. litter wt., kg.	12.9	13.3	13.5	0.87
21-DAY RECORDS:				
No. pigs/litter	9.2	9.4	8.6	0.43
Avg. pig wt., kg.	5.1	5.3	5.2	0.20
Avg. litter wt., kg.	46.8	48.6	44.8	3.80

Late Pregnancy

Two of the 14 gilts subjected to heat stress during late pregnancy (102 to 110 days postbreeding) died during chamber confinement. Both gilts were pregnant at death and death was attributed to heat prostration. A marked detrimental effect of heat stress at this time is exhibited in Table VIII. Gilts stressed during late pregnancy farrowed an average of 4.4 fewer pigs per litter than did the control gilts and 4.7 fewer than gilts maintained outside ($P<.01$). Based on the average ovulation rate of 14.8 for all gilts slaughtered, this means that these gilts farrowed only 40.5% live pigs of the estimated potential while the control gilts farrowed 70.9% of their potential. Heat stressed gilts had significantly more ($P<.01$) dead pigs per litter with 46.4% of the pigs being dead. Due to litter size differences, average litter weights were considerably less ($P<.01$) for these gilts. Although not significant, pig weights at birth tended to be slightly less for the heat-stressed group.

The differences obtained in productivity at farrowing were even more marked at 21 days. The survival rate for the first 21 days was 71.7% for the heat stressed gilts compared to 88.5% for the control chamber gilts and 80.4% for the outside control gilts. Litter size and weights for the heat-stressed groups were only about half the magnitude of those for the control groups. Individual pig weights at this time were not significantly different but there was tendency for pigs raised by heat-stressed sows to be slightly lighter.

Comparing responses of mid pregnancy and late pregnancy control groups to gilts maintained outside full term, indicates that there

TABLE VIII

REPRODUCTIVE PERFORMANCE OF GILTS CONFINED TO CHAMBERS DURING LATE PREGNANCY COMPARED TO THOSE MAINTAINED OUTSIDE THROUGHOUT PREGNANCY

	Hot Chamber	Control Chamber	Outside	Standard error
No. gilts allotted	14	14	14	
No. farrowed	12	14	14	
FARROWING RECORDS:				
Live pigs/litter	6.0[a]	10.4[b]	10.7[b]	0.76
Dead pigs/litter	5.2[a]	0.4[b]	1.0[b]	0.62
Avg. pig wt., kg.	1.2	1.4	1.3	0.05
Avg. litter wt., kg.	8.6[a]	13.6[b]	13.5[b]	0.87
21-DAY RECORDS:				
No. pigs/litter	4.3[a]	9.2[b]	8.6[b]	0.43
Avg. pig wt., kg.	5.1	5.5	5.2	0.20
Avg. litter wt., kg.	29.1[a]	50.8[b]	44.8[b]	3.80

[a,b]Values within rows with different superscripts significantly different ($P<.01$).

is no evidence of confinement being a stress factor in this study. There were no significant differences between these groups for the traits evaluated.

CHAPTER V

SUMMARY

A total of 126 sexually mature gilts were used to study the effects of high ambient temperatures during early, mid and late pregnancy. The study included two replications of nine treatments with the first 63 gilts bred in August of 1968 and the second group of 63 bred in February of 1969. Gilts were randomly allotted to each treatment at the time of breeding with a total of 14 gilts in each treatment. One group in each replication was maintained in outside pasture lots full term, while the other gilts were subjected to either the control chamber (23.3°C continuously) or the hot chamber (37.8°C for 17 hours and 32.2°C for 7 hours) for a period of 7 days during the first week of gestation, second week of gestation, mid pregnancy or late pregnancy. The two 12 ft. by 12 ft. temperature controlled rooms at the Ft. Reno Livestock Research Station were used in this study.

Rectal temperatures for control gilts in this study were comparable at all times and showed very little within day variation. Mean rectal temperatures for gilts placed in the hot chamber remained well above normal until around day six of confinement at which time an acclimation to the hot environment was noted. The minimum body temperature during confinement for stressed gilts in the early and mid pregnancy groups was not significantly different from controls during the last few days of confinement. The degree of acclimation was less distinct for the late pregnancy group.

Gilts studied during the first or second week of gestation were slaughtered at 30 days postbreeding and their reproductive tracts were analyzed for corpora lutea numbers, embryo numbers and embryo size. Eight of the 14 (57.1%) gilts exposed to the hot chamber during the first week postbreeding and 11 of 14 gilts (78.6%) exposed to the hot chamber during the second week were pregnant at 30 days. All nine gilts that failed to conceive on first service did settle when rebred after confinement suggesting a detrimental effect of high ambient temperature on conception rate during early pregnancy.

Differences in ovulation rates among treatment groups were noted, but they were not considered to be associated with the treatment imposed. Control-chamber gilts had more ($P<.01$) viable embryos than either of the heat stressed groups. A marked disadvantage was shown for gilts exposed to high temperatures during the second week of gestation with 4.5 fewer embryos ($P<.01$) than gilts stressed during the first week and 5.9 fewer than the control group. Although the differences were not significant, there was a tendency for embryo lengths to be smaller for heat stressed gilts.

Control-chamber gilts during mid and late pregnancy, as well as the gilts maintained outside in pasture lots, all responded comparably in this study. There were no significant differences in the variables measured for these groups, therefore the control groups were combined for comparison purposes. From this it also was concluded that confinement by itself was not a stress factor in this study.

Gilts stressed during mid pregnancy (day 53 through 61 postbreeding) showed little, if any, signs of heat stress effects. There were no significant differences between hot chamber and control chamber responses

at this time. This indicates a tolerance of gilts to high ambient temperatures during mid pregnancy.

Two of the 14 gilts (14.3%) subjected to heat stress during late pregnancy (102 to 110 days postbreeding) died during chamber confinement due to heat prostration. The remaining 12 stressed gilts averaged 4.4 fewer live pigs per litter than the control gilts and 4.7 fewer live pigs than gilts maintained outside ($P<.01$). Litter size and weights for heat stressed groups were only about half that of control groups. The 56 gilts slaughtered 30 days postbreeding had an average of 14.8 corpora lutea so this means that the gilts stressed in late pregnancy farrowed only 40.5% of their estimated potential compared to 70.9% of this potential for the control groups. Heat stressed gilts farrowed an average of 46.4% dead pigs per litter and consequently average litter weights were considerably less ($P<.01$) for these gilts.

Survival rate to 21 days was 71.7% for the heat stressed group, 88.5% for the controls and 80.4% for outside control gilts. Due to these differences in survival rate along with the initial differences noted at birth, litter sizes and weights were considerably less ($P<.01$) for those heat stressed during late pregnancy. There was a tendency for individual pig weights to be slightly less for heat stressed gilts but these differences were not significant.

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APPENDIX

TABLE IX

ANALYSES OF VARIANCE FOR NUMBER OF LIVE EMBRYOS AND AVERAGE EMBRYO LENGTH

Source	df	Mean Square	
		Live Embryos	Embryo Length
Total	47		
Mean	1		
Covariable[1]	1	92.675	1042.872
Replication	1	1.668	0.399
Treatment	3	90.076**	12.341
Error	41	1.201	13.290

[1]Covariables were either number of corpora lutea held constant for number of live embryo analysis, or days pregnant held constant for embryo length analysis.

**Significant ($P<.01$) Treatment mean differences were subjected to Duncan's Multiple Range Test described by Steele and Torrie (1960).

TABLE X

ANALYSES OF VARIANCE FOR NUMBER OF PIGS

BORN LIVE AND DEAD PER LITTER

Source	df	Mean Square	
		Live Pigs	Dead Pigs
Total	67		
Reps	1	3.215	16.515
Within Treatment	6	7.614	4.948
Rep x Block	6	9.614	4.681
Treatments	4	57.736*	50.878*
Rep x Treatment	4	0.821	2.050
Error	46	8.169	5.328

*Significant (P<.01)

TABLE XI

ANALYSES OF VARIANCE FOR LITTER WEIGHTS

AT BIRTH AND 21 DAYS

Source	df	Mean Square	
		Birth	21 Days
Total	67		
Reps	1	1.857	6606.491
Within Treatment	6	52.643	632.672
Rep x Block	6	66.004	1497.138
Treatments	4	519.316*	9152.581*
Rep x Treatment	4	17.819	1009.397
Error	46	51.498	981.709

*Significant (P<.01)

TABLE XII

ANALYSES OF VARIANCE FOR AVERAGE PIG

WEIGHTS AT BIRTH AND 21 DAYS

Source	Birth		21 Days	
	df	MS	df	MS
Total	65		64	
Reps	1	0.094	1	11.890*
Within Treatment	6	0.171	6	3.430
Rep x Block	6	0.224	6	1.739
Treatments	4	0.144	4	1.765
Rep x Treatment	4	0.104	4	9.698*
Error	44	0.172	43	2.600

*Significant (P<.05)

TABLE XIII

AVERAGE RECTAL TEMPERATURES[a] AND COEFFICIENTS OF VARIATION[b] FOR GILTS CONFINED DURING THE FIRST WEEK OF GESTATION

	Hot Chamber				Control Chamber	
	Minimum (4pm)		Maximum (8pm)			
Day	Temp	CV	Temp	CV	Temp	CV
1	104.31	1.65	105.67	0.57	102.21	0.72
2	103.45	1.48	105.24	1.45	101.99	0.61
3	103.37	1.18	105.31	0.78	101.95	0.86
4	103.36	1.08	104.81	0.71	102.04	0.54
5	102.95	1.02	104.61	1.05	102.16	0.63
6	102.95	1.32	104.21	0.95	102.15	0.41
7	102.46	1.01	104.02	1.18	102.13	0.52
8	102.17	0.92	104.14	1.21	101.89	0.47

[a]Temperatures expressed in degrees Fahrenheit.

[b]Coefficients of variation expressed in percentage.

TABLE XIV

AVERAGE RECTAL TEMPERATURES[a] AND COEFFICIENTS OF VARIATION[b] FOR GILTS CONFINED DURING THE SECOND WEEK OF GESTATION

Day	Hot Chamber Minimum (4pm) Temp	CV	Maximum (8pm) Temp	CV	Control Chamber Temp	CV
1	103.53	0.50	105.18	1.15	101.84	0.39
2	103.12	1.72	105.11	1.22	101.57	0.35
3	102.86	1.61	104.84	1.32	101.44	0.37
4	102.21	1.40	104.27	1.08	101.64	0.45
5	102.10	1.61	104.17	1.08	101.51	0.46
6	101.36	1.25	103.64	1.01	101.34	0.42
7	101.30	1.09	103.42	0.97	101.36	0.50
8	101.54	1.25	103.69	1.00	101.30	0.38

[a]Temperatures expressed in degrees Fahrenheit.

[b]Coefficients of variation expressed in percentage.

TABLE XV

AVERAGE RECTAL TEMPERATURES[a] AND COEFFICIENTS OF VARIATION[b] FOR GILTS CONFINED DURING MID PREGNANCY

Day	Hot Chamber Minimum (4pm) Temp	CV	Hot Chamber Maximum (8pm) Temp	CV	Control Chamber Temp	CV
1	103.19	0.80	104.80	0.89	101.39	0.37
2	102.31	1.06	104.59	0.81	101.26	0.41
3	102.87	1.25	104.66	1.26	101.33	0.36
4	102.26	1.26	104.64	1.18	101.44	0.37
5	101.84	0.86	104.23	0.90	101.42	0.28
6	101.61	1.01	103.86	1.31	101.34	0.28
7	101.47	1.23	103.61	1.20	101.34	0.34
8	101.65	0.97	103.65	0.93	101.24	0.40

[a]Temperatures expressed in degrees Fahrenheit.

[b]Coefficients of variation expressed in percentage.

TABLE XVI

AVERAGE RECTAL TEMPERATURES[a] AND COEFFICIENTS OF VARIATION[b] FOR GILTS CONFINED DURING LATE PREGNANCY

Day	Hot Chamber Minimum (4pm) Temp	CV	Hot Chamber Maximum (8pm) Temp	CV	Control Chamber Temp	CV
1	104.01	1.30	104.99	1.43	101.38	0.36
2	103.30	1.31	105.69	0.94	101.35	0.30
3	102.85	1.46	105.30	0.88	101.41	0.37
4	102.35	1.05	105.03	0.78	101.44	0.36
5	102.15	0.86	105.15	1.22	101.39	0.26
6	102.34	1.11	104.23	0.94	101.42	0.51
7	102.24	1.17	104.40	1.04	101.28	0.36
8	102.28	0.89	104.88	0.79	101.53	0.41

[a]Temperatures expressed in degrees Fahrenheit.

[b]Coefficients of variation expressed in percentage.

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